Develop a Hybrid Coordinate Ocean Model with Data Assimilation Capabilities

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LONG-TERM GOALS

To develop data-assimilating capability for HYCOM, the hybrid version of University of Miami's Isopycnic Coordinate Ocean Model.

OBJECTIVES

a) To develop a methodology for assimilating temperature profiles from XBTs that accommodates the peculiarities of the hybrid system of vertical coordinates, allowing density to be corrected at fixed pressure levels where the coordinate is pressure-like, allowing interface pressures to be corrected when the coordinate is density-like, and allowing both to be corrected in the transition zone.

b) To compare the model-state to observations and infer error statistics and influence functions.

c) To develop codes for implementing this methodology.

APPROACH

Companion salinity profiles are to be estimated and used to estimate density profiles from which data for layer-interface pressures and layer potential-densities can be obtained. At first, error-statistics, which govern the nature of the data-based corrections to the model state, are to be postulated so that assimilation codes can be made functional; later, they are to be based on model-data comparisons. The method is to be sufficiently flexible to allow for incorporation of other types of data, in particular those from satellite-based observations.

WORK COMPLETED

a) The design for the data-assimilation methodology exists and is being tested.

b) Much of the preprocessing system to estimate companion profiles and layer/interface values has been implemented, although additional software engineering is needed.

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c) Initial efforts have been made toward developing procedures for comparing model to data and inferring influence functions from error statistics.

d) A paper describing the methodology is in preparation.

RESULTS

This project is one component of the NOPP consortium for developing a data-assimilating ocean model based on a hybrid vertical coordinate. The focus of this component has been on the assimilation of in situ hydrographic data to correct the model state.

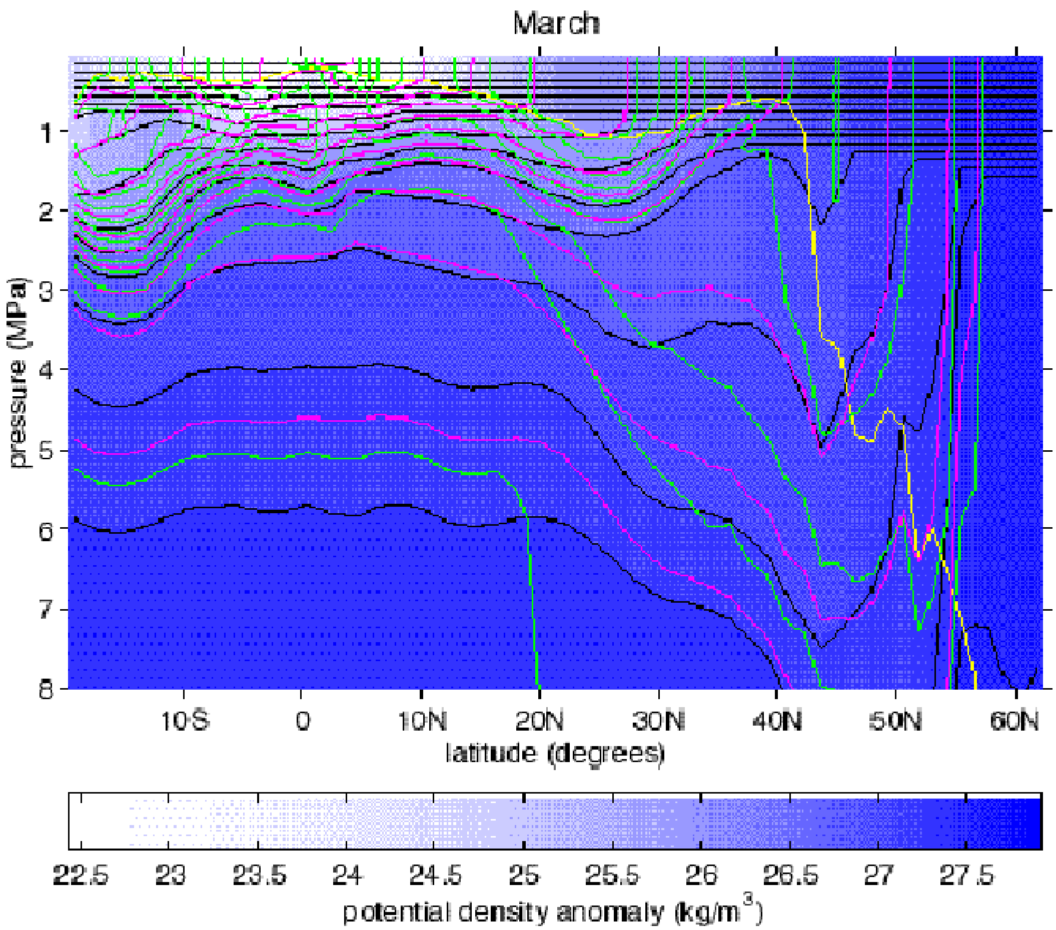

Figure 1. Vertical section at 25° W from HYCOM simulation forced for 30 years with climatological annual cycle of surface fluxes. Shades of blue indicate variations of potential density with pressure and latitude. Pressures of layer interfaces are indicated by black curves, contours of potential temperature (2° C spacing) by magenta, contours of salinity (0.2 psu spacing) by green, and bottom of the mixed layer by yellow.}

The model's objective is to exploit the fact that the ocean is stratified and thus can largely be viewed as consisting of layers of water that move to preserve their densities (Bleck and Chassignet, 1994). However, near the surface where mixing is important, this description breaks down and

density is less useful as a coordinate. The idea of a hybrid coordinate model is to have layers that are density-like (specified potential density) at depths where the ocean is stratified and pressure-like (specified thickness) where it is well mixed, smoothly changing from one aspect to the other (figure 1). The seasonal cycle of the mixed layer and upper thermocline requires that the nature of the layers change both with time and with location. While this formulation offers advantages for modeling, it also imposes challenges for data assimilation.

The bulk of the data available for assimilation pertain to the upper ocean. XBT casts, which comprise the bulk of the in situ data, span the pressure-like, transition, and density-like regions. Similarly, altimetric data from satellites reflect the thicknesses of layers in all three regions. In the pressure-like layers, density must be inferred from the observations to correct the model, while layer thicknesses must be inferred when the layers correspond to specified densities. The data-assimilating methodology must determine the nature of the layers from observations in order to know to what extent the model state needs to be corrected. The design that has been developed addresses this issue directly.

Unfortunately, density is not directly observed. While temperature, which is observed, is a major determinant of density, salinity cannot be ignored. To infer where layer interfaces should be, a salinity strategy is necessary. Some method is needed to estimate companion salinity for temperature observations. For expediency, so that other aspects of the project can progress, salinity is being estimated from the climatological mean conditions for the location and time of year. Better estimates are achievable (Hansen and Thacker, 1999) but to do so would require a separate project.

The focus of this sub-project has been on the use of XBT data, because they provide the most direct information about the vertical structure of the ocean and thus about the nature of the hybrid layers. The ultimate goal is to use all types of data, combining the horizontal information provided by satellite-based observations with the information about vertical structure from in situ soundings.

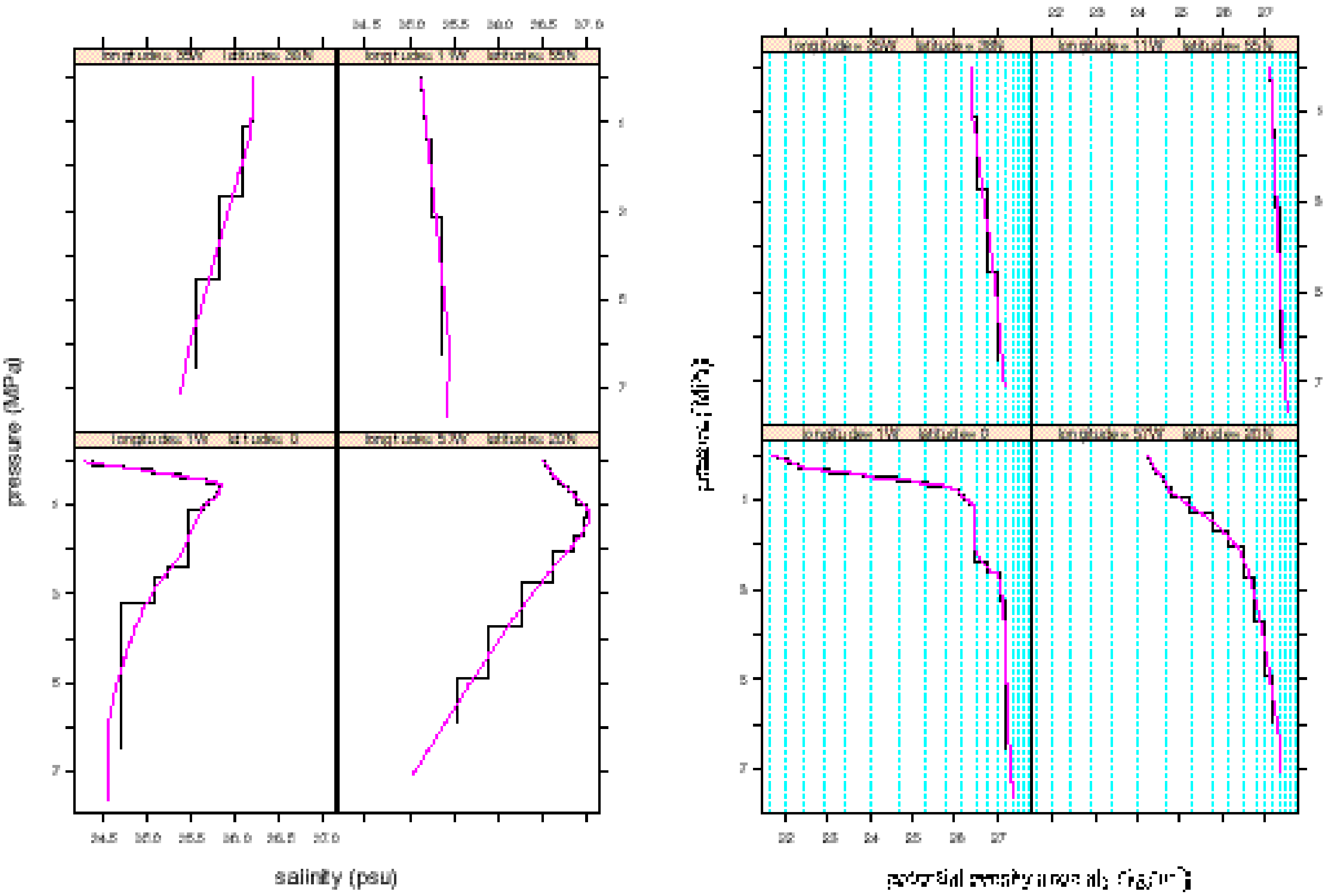

Figure 2. Left panel: Companion salinity profiles (magenta) at locations of four XBT casts in March, 1995 and their approximation for HYCOM as layer averages (black). Right panel: Companion potential-density profiles (magenta) based on companion salinity profiles and their layer averages (black). Target values of potential density for the model's layers are indicated (cyan) for comparison.

The methodology for pre-processing XBT data is illustrated in figure 2. For each XBT cast climatological salinity is interpolated to depths where temperature is measured (left panel). The equation of state of sea water is then used to estimate potential density (right panel) and potential temperature (not shown --- essentially the same as observed temperature) at these depths, providing companion profiles for variables of the model. Depth is converted to pressure (vertical axis) using the local value for the acceleration of gravity. The identification of the positions of layer interfaces (horizontal steps) is done in a way that is similar to that used for initializing the layer structure of the non-hybrid version of the model from climatological data, but modified so that "zero-thickness" layers are inflated to the minimal allowed thickness. The model is formulated in terms of target potential densities for the layers. Starting from the top, as long as water is heaver than a target value, minimum layer thickness is specified. Once sufficiently dense water is encountered, allowing a layer of target density to be constructed with more than the minimum allowed thickness, it is. This procedure is repeated to the depth of the cast. (No effort has been made to estimate the

depth of the first interface below the bottom of the cast.) Then, layer values are evaluated as integrals from one interface to the next. This produces ``observed" values of potential temperature and potential density for the observed layers and values of pressure for the interfaces separating them.

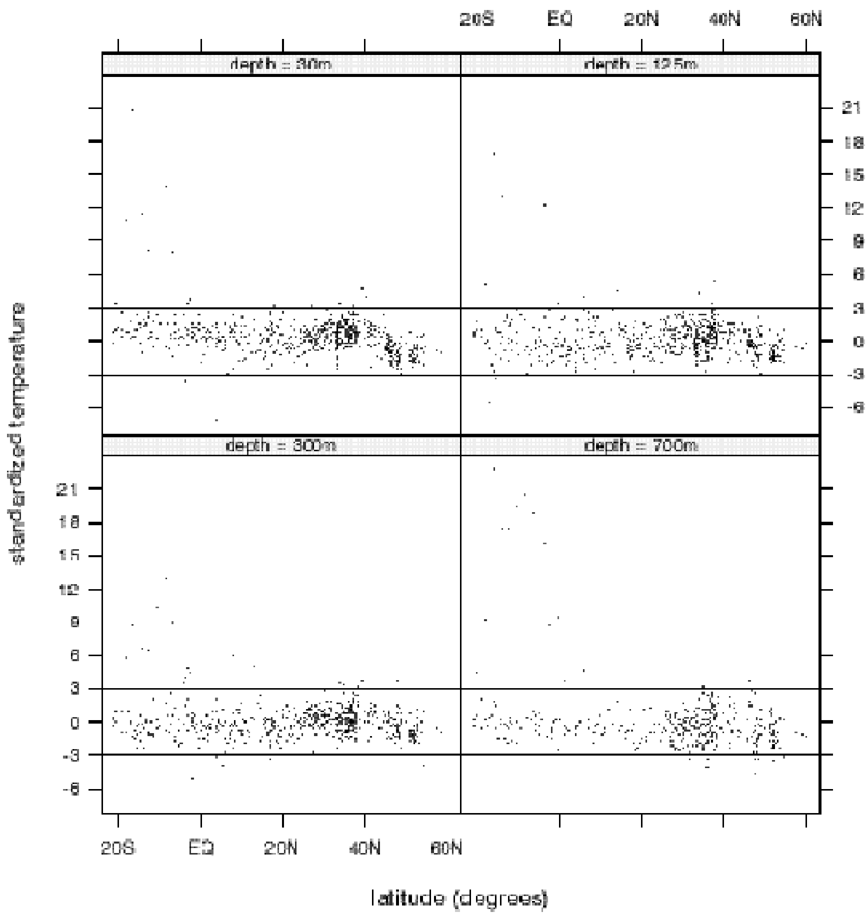

Figure 3. Departure of observed temperatures for March 1995 from the March climatological mean relative to the local climatological standard deviation vs. latitude of the XBT cast for four different depths. All observations within three standard deviations of the local climatological mean lie within the two horizontal lines.

An important concern is data quality. The XBT data that are being used for this developmental work are the same as have been used routinely at the National Centers for Environmental Prediction, as they had already undergone quality control. However, when compared to climatology (figure 3), a sizable fraction of the data were found to depart from climatology by more than four standard deviations. This suggests that a supporting quality-control project is needed, so that the data that are to be pre-processed for assimilation can be used without reservation.

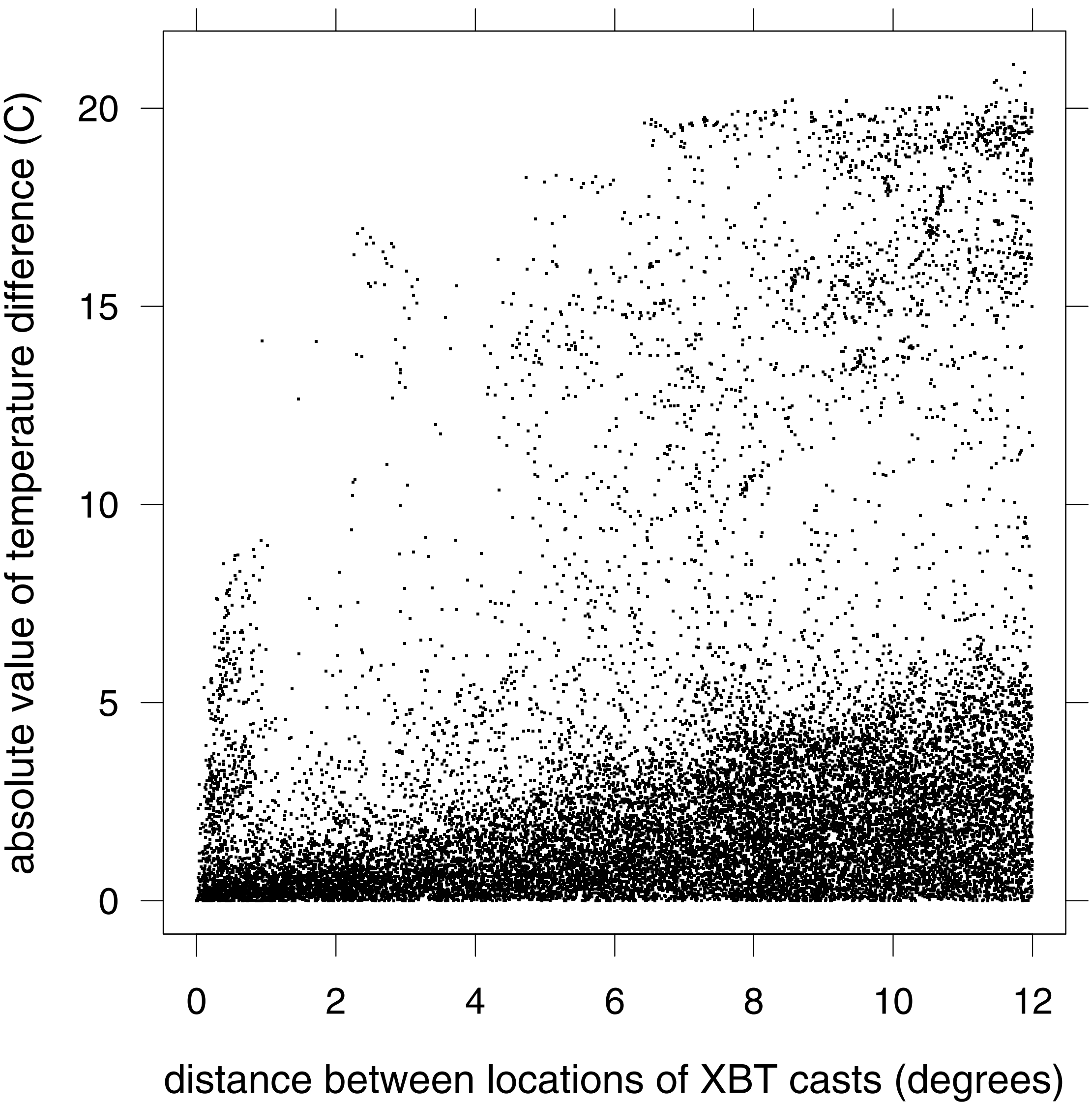

Figure 4. Absolute temperature differences at 30 m for pairs of XBT soundings vs. distance measured as square root of sums of squares of longitidunal and latitudinal separations. Large differences at small separations span the Gulf Stream and those at larger distances span the Gulf Stream extension. All data shown fall within the three-standard-deviation lines of figure 3.

Once the data have been pre-processed to give model-relevant values, they can be used to correct the model state. A variety of techniques are available (Malanotte-Rizzoli, 1996), most of which are based on the error statistics of the model state. The approach taken here is to maintain flexibility, using simple, easy to implement methods in the beginning while allowing for increasing sophistication in the future. Because early simulations have focused more on getting the hybrid model working than on model-data comparisons, details of the error covariances are not yet suited to inferring influence functions for spreading the corrections away from the observations. Figure 4 shows that the range of influence should reflect the observed contrasts. Initial efforts are focusing on parameterizing error covariances in terms of local climatological variability.

IMPACT/APPLICATIONS

This research should lead to a facility for producing model-based analyses of hydrographic data. Low-resolution analyses can be used to provide initial conditions for high-resolution models and for studying climate. At high resolution, this approach can be extended to incorporate detailed horizontal information provided by satellite-based observations.

TRANSITIONS

The assimilation codes that are under development will be made available to the wider oceanographic community as a part of the HYCOM modeling facility.

RELATED PROJECTS

This project is one component of the NOPP consortium for developing a data-assimilating ocean model based on a hybrid vertical coordinate.

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